Titan and Europa: Candidates as Habitable Moons for Humanity

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Author Bio

Daniel Hu is a student at Brunswick School in Connecticut. He is passionate about physics and astronomy, especially astrophysics. He started his own astronomy club at school to inspire people to discover the universe above their heads. Daniel enjoys volunteering at a local observatory, where he operates their telescope and teaches the public about the night sky. He also likes to conduct research on asteroid occultations. He has his own telescope setup, and regularly takes part in astrophotography, particularly nebulae and star clusters. Outside of academics, he is an avid hockey player for his high school team, one of the top in the nation.

Abstract

One major reason humans want to explore potentially habitable extraterrestrial objects is to ensure the survival of our species. Moons of Saturn and Jupiter, such as Titan and Europa, are less known compared to Mars and Venus but have promising features that could make them habitable for humans. Titan has a thick atmosphere similar to Earth's, and Europa is speculated to have a vast subsurface liquid water ocean. However, challenges such as long travel distances and cold surface temperatures are also present on these moons. This paper will analyze features in depth on Titan and Europa that make them ideal candidates as potential places that could support human life. Challenges of exploring and inhabiting these moons are also considered. Two future missions to Titan and Europa, Dragonfly and Europa Clipper, their instruments and information they can gather, and what these new discoveries can mean for human exploration are also discussed.

Keywords: Titan, Europa, Extraterrestrial Habitability, Subsurface Ocean, Atmosphere, Dragonfly missions, Europa Clipper mission, Sensing With Independent Micro-Swimmers

Introduction

On Earth, problems such as global warming, resource depletion, and even human conflict threaten the survival of our species. Although these problems may not lead to immediate catastrophe, they are problems that one should be prepared for. In terms of identifying candidates for habitable planets, Mars and Venus have received a large amount of attention in past and present missions. For comparison, NASA has had 23 missions to Mars (NASA Mars Exploration Program, 2021), while only six to Europa (NASA Europa Clipper, 2014). These two planets seem to have conditions that could have harbored some sort of life in their earlier years: water and more moderate climates. However, Mars and Venus are anything but habitable in the present day. Mars has no atmosphere and freezing temperature, while Venus has a suffocating atmosphere and is hot enough to melt lead (NASA Solar System Exploration, 2022).

Titan and Europa are moons of Saturn and Jupiter, respectively, and have promising features to sustain human life. Heat is important as a suitable amount of it allows extraterrestrial objects to have liquid water. Both Titan and Europa generate heat internally through a process called tidal heating. Tidal heating is the result of the larger planet compressing and contracting the much smaller moon, causing friction inside the planet to generate heat (Lunine, 1997). Europa, for example, is speculated to have an enormous subsurface liquid water ocean as a result of tidal heating (NASA Europa Clipper, 2014). Titan is also believed to have a subsurface ocean, but it also has a thick atmosphere. While the origins of Titan's atmosphere is still being researched, having one is important to sustain life, as will be discussed in this paper. These two qualities make Europa and Titan attractive candidates for habitability. However, these moons also present challenges for exploration and serving as habitable places. These moons are further away than neighboring planets, causing both transportation time and cost to increase dramatically. Jupiter has the strongest radiation belt out of all the planets and consequently its moons receive dangerously high doses of radiation (Roussos, 2022). Surface temperatures are well below freezing and oxygen is not present in the atmosphere (NASA Solar System Exploration, 2022). With all that said, Titan and Europa have conditions that make them ideal candidates as habitable places for humans in the future, and will be explored further in future missions.

Different Moons of the Solar System

Moon Definition

A moon is a type of extraterrestrial object that orbits a larger planet that has not met the three criteria for being classified as a planet: orbit the Sun, have sufficient mass so its gravitational force is enough to form a roughly round shape, and have cleared its path of similar sized objects (IAU Resolution B5, 2006). While Earth's Moon is spherical, the gas giants have moons that are unusual looking and/or irregular. For example, Saturn's Prometheus is extremely elongated while Pan resembles a ravioli (Leleu, 2018). Jupiter has a number of irregular moons that were formed from asteroids captured by its immense gravitational field, and have large, highly eccentric and/or inclined orbits. Saturn's unusual looking inner moons were formed from collisions of similar sized moonlets (Leleu, 2018). These irregular moons are noticeably different from regular moons, which formed along with the parent planet from an accretion disk and have roughly circular and uninclined orbits (Jewitt, 2007).

Earth's Moon

Earth's Moon has been studied extensively in human history, and is a stark contrast to Titan and Europa. The Moon is believed to have formed through what is known as the impact theory. Scientists believe that through evidence between the similarity of lunar rocks and those on Earth, the moon was formed from the debris of an impact by a large body, Theia, on Earth (Jones, 2000). Earth's Moon has been explored extensively by many countries, with much data and information collected. Based on all of the data and research, the Moon is a relatively barren and desolate place. Its atmosphere is so thin that the surface can essentially be considered a vacuum. Because of this lack of atmosphere, the surface pressure is 2.96 x 10^-15 atm (Stern, 1999), compared to the surface pressure of Earth, which is one atm. With no source of internal heat and the lack of an atmosphere, temperatures on the moon's surface range from 127 C to -173 C (NASA Solar System Exploration, 2022). Deadly amounts of radiation from the Sun and outer space also blast the Moon's surface. Water has been found on the

surface of the Moon near the poles, where it exists as rock hard ice inside of permanently shadowed craters. There is so little water discovered on the Moon from missions that the Sahara Desert has 100 times as much. (Wasser, 2020). All in all, the Moon lacks features that make it possible for humans to survive for long periods of time.

Titan

Titan is the largest moon of Saturn, larger than Mercury and similar in size to Mars. Titan is one of the few objects in the solar system that resembles Earth. Its dense atmosphere is made of mostly nitrogen (95%), with hints of methane (5%) and trace amounts of other carbon-rich compounds (NASA Solar System Exploration, 2022). Having a dense atmosphere benefits Titan in many ways. This dense atmosphere, along with Saturn's magnetosphere, protects Titan from dangerous radiation from the Sun. The high density creates a surface that is around 60% more pressurized than Earth's, making Titan the only object which has a similar surface pressure to Earth (NASA Solar System Exploration, 2022). As a result of this high pressure, humans can walk around on Titan without the need of a pressurized suit. Liquid methane lakes and oceans are present on the surface, making Titan the only other object besides Earth to have liquids on the surface. The methane on Titan has a cycle similar to the water cycle on Earth, going through the process of starting as a liquid, evaporating, and then raining back down (NASA Solar System Exploration, 2022). This abundance of methane can potentially be used as a source of energy, as methane is a key natural gas here on Earth. Electricity is generated through methane when the heat produced from burning methane powers a turbine, which in turn generates electricity (Kondaveeti, 2019). Methane in the atmosphere also acts as a greenhouse gas, which heats the moon. Besides the abundance of features above the surface, Titan is also speculated to contain a subsurface liquid ocean as a result of tidal heating. This ocean, along with the rest of Titan, will be studied further in the Dragonfly Mission. The author believes that new discoveries from the Dragonfly Mission will further enhance Titan as a candidate for humans to inhabit.

Disadvantages of Titan

With all of these conditions that are potentially suitable for humans, there are challenges on Titan. The most obvious one is the cold temperature on the surface, with an average of -180 degrees Celsius (NASA Solar System Exploration, 2022). At this temperature, humans can not survive without protection, and any form of shelter would need to be more cold resistant than those used on Earth. While Titan has a robust atmosphere, it is made of mostly nitrogen and lacks oxygen. Oxygen can potentially be split from the subsurface water ocean, but doing so is difficult and energy consuming. Another issue is that Titan only has around 14% of Earth's gravity (NASA Solar System Exploration, 2022). Spending long periods in low gravity environments can cause muscle loss and a decrease in bone density, among other negative impacts (Wolfe, 1992). Titan may also host some sort of life, which can develop into a problem if humans come into contact with them, for example harmful microorganisms. Tholins are a type of organic compounds that form after high energy particles from cosmic rays split apart methane and nitrogen in the atmosphere. These compounds are rich in nitrogen and carbon, which provide the building blocks for life (Waite, 2007). On Earth, bacteria called anaerobic methanotrophs consume methane and single carbon compounds to survive (Guerrero-Cruz, 2021). The liquid methane and tholins on Titan can provide suitable conditions for life to arise. While finding extraterrestrial life forms is exciting, it can also be dangerous for humans to coexist with them on the same moon as humans and these potential life forms can negatively impact each other. All in all, Titan is a great candidate for humans to inhabit in the future with its abundance of promising features, some of which even resemble Earth. However, Titan is not without flaws, and will have to be explored further. NASA is in the works of making a lander mission specifically to explore Titan in more detail than previously.

Dragonfly Mission

The Dragonfly Mission was proposed by John Hopkins's Applied Physics Laboratory to NASA in 2017 and selected as the fourth mission in the New Frontiers program. It is set to launch in 2027 and arrive at Titan in 2034 (JHUAPL Dragonfly, n.d.). The purpose of the Dragonfly mission is to search for extraterrestrial life and habitability on Titan. Dragonfly will be a dual-quadcopter design to take advantage of aerial travel, made easy by Titan's thick

atmosphere and low gravity. Dragonfly can cover tens of miles during the day and recharge during the night. Sunlight does not penetrate Titan's thick atmosphere easily, so Dragonfly cannot use solar panels as an effective power source. Instead, it uses a Multi-Mission Radioisotope Thermoelectric Generator, the same one as on the Curiosity rover on Mars (JHUAPL Dragonfly, n.d.). A Multi-Mission Radioisotope Thermoelectric Generator works by converting the heat generated from the decay of plutonium-238 into electricity using the temperature difference between two different, electrically conductive materials in a closed circuit (NASA Radioisotope Power Systems, 2022). Scientists took data from the Cassini mission and analyzed it to predict the optimal timing for a calm weather period, as well as identifying a landing site. Dragonfly will land at the Shangri-La dune fields, which is similar to the dunes in Namibia and offers a large sampling of materials. After landing, Dragonfly will perform flying missions of more than five miles to reach the Selk impact crater. Along the way, Dragonfly will use instruments such as a mass spectrometer, meteorology sensors, and cameras. These will enable Dragonfly to collect data on both the surface composition and atmospheric conditions, as well as seismic activity to study subsurface activity and structure (JHUAPL Dragonfly, n.d.).

Titan Habitability

Planetary scientist Dr. Amanda Hendrix, a senior scientist at the Planetary Science Institute, expressed her opinions about Titan as a habitable world in her article "Confession Of A Planetary Scientist: 'I Do Not Want To Live On Mars'". The author agrees with most, if not all, of the logical conclusions reached in the paper. For example, the line "these damaging particles cannot make it to Titan's surface; they're absorbed by the atmosphere, meaning that it's a safe environment for humans" (Hendrix, 2017) makes perfect sense as ultraviolet radiation is deadly to humans in space. Titan's thick atmosphere blocks these particles that would otherwise easily make the moon inhabitable. Another point that the author agrees with is the acknowledgement that sending humans to Titan is still a process in the making. Many challenges are in the way, such as low gravity and the lack of a food source. A mission like Dragonfly will allow scientists to gain further knowledge of the moon, and the author believes any more information will only strengthen Titan's candidacy as a habitable moon for humans.

Europa

Europa is a Galilean moon of Jupiter characterized by its large amount of water, both in ice form and liquid form. Europa is around 5.2 AU from the Sun, resulting in sunlight being 25 times fainter there than on Earth and causing temperatures on Europa to average around -160 degrees Celsius (NASA Europa Clipper, 2014). A rock-hard icy water shell, estimated to be 10 to 15 miles thick, covers the entire moon (Nasa Europa Clipper, 2014). However, there is strong evidence from the Galileo mission that Europa has a vast subsurface liquid water ocean. Data gathered from the Galileo mission showed that Jupiter's magnetosphere is disrupted around Europa. The best explanation for this is that Europa is inducing a magnetic field internally, most likely through the rotation of a salty liquid water ocean underneath its ice surface (NASA Europa Clipper, 2014). Similar to Titan, a subsurface liquid ocean water can be made possible by the heat generated through tidal heating. Salty water is not drinkable by humans, but fresh water can be generated through a process called ocean thermal energy conversion (OTEC), a type of technology used on Earth to both desalinate ocean water and generate electricity. OTEC works by using the difference in temperature of salt water, which should be present on Europa. Warm salty water is turned into steam by reducing its pressure. This steam drives a turbine generator to produce electricity, before being turned back into a liquid in a condenser cooled with cold water. While heating and condensing sea water, salt and other impurities are removed to produce fresh water (Ocean thermal energy conversion, n.d.). Besides having a speculated ocean, Europa's surface may hold more than it seems. While the surface appears mostly smooth, images from NASA's Galileo spacecraft revealed jagged double ridges spanning thousands of kilometers and rising hundreds of meters tall (NASA Solar System Exploration, 2022). These double ridges may be formed by warm liquid water rising through the ice, forming a pocket inside the sheet of ice. This pocket of liquid water inside the ice will have temperatures higher than the surface. Almost similar to an igloo, these pockets can protect humans from the frigid cold and high levels of radiation on the surface. Europa also has a thin atmosphere that contains oxygen, but humans cannot breathe without oxygen tanks as the atmosphere is too tenuous.

Europa's biggest strength is its large subsurface liquid water ocean and pockets of warmer water within the icy surface. However, frigid temperatures, high levels of radiation, and a lack of oxygen are among main issues humans face. NASA is planning the Europa Clipper mission to explore the ocean world in further detail.

Europa Clipper Mission

Europa Clipper is a NASA mission set to launch in 2024. It will be the first NASA mission to exclusively study a moon besides Earth's. Europa Clipper will send a spacecraft into orbit around Europa, where it will spend three years flying around Europa 45 times (NASA Europa Clipper, 2014). The spacecraft has an arsenal of instruments to study the icy moon. Its primary mission is to determine if Europa has conditions suitable for life, which scientists highly suspect it does. Europa Clipper's ten instruments can be grouped into four sets based on their function. Cameras and spectrometers create high resolution images and maps of Europa's surface and atmosphere (NASA Europa Clipper, 2014). These images can allow scientists to further explore sections of the surface such as ridges in the ice sheets, as well as identifying areas for future lander missions. Ice penetrating radar, a magnetometer, and plasma sensors allow the spacecraft to explore the ocean and interior of the moon. The plasma sensor studies the distortions of Europa's magnetic field caused by Jupiter, and the magnetometer studies the magnetic field induced by Europa. Scientists will use the data collected by the plasma sensor to factor out any distortion from the data by the magnetometer to achieve a cleaner final result. This final result can produce proof of a liquid water ocean underneath the surface, as well as measure its depth, salinity, and the thickness of the ice shell (NASA Europa Clipper, 2014). A thermal imaging camera will identify regions of warmer ice (NASA Europa Clipper, 2014). By determining where warmer ice exists and if ridges are present at these locations, there is further proof that ice pockets exist underneath these ridges in the ice sheet. A dust analyzer and mass spectrometer measure the chemical properties of particles in Europa's atmosphere (NASA Europa Clipper, 2014). These instruments will provide valuable insight into the possibility of Europa harboring life, and also explore the feasibility of human settlement and future lander missions.

Europa Habitability

Dr. Tom Kerwick stated in his journal article "Colonizing Jupiter's Moons: An Assessment of Our Options and Alternatives" that Europa poses an interesting balance between having many great and also less than ideal qualities. The author agrees with the idea of Europa having a mix between good and bad factors. For example, the line "At 670,000 km from Jupiter, Europa receives 540 rem of radiation per day from the Jovian belts" (Kerwick, 2012, p.12) proves that Europa has harsh surface conditions that would make unshielded living impossible. Other parts of the articles are more optimistic, as in "The abundance of water is significant not only as a source of drinking water, but it could also be broken down to provide breathable oxygen" (Kerwick, 2012, p.12). Europa is an interesting case. It has many features that make it seem perfect for human colonization, yet it also has many that makes it inhabitable. Future missions like Europa Clipper will allow scientists to gain more information to unravel the mysteries of the moon.

Sensing With Independent Micro-Swimmers

Sensing With Independent Micro-Swimmers (SWIM) is a concept in development at NASA's Jet Propulsion Laboratory (Greicius, 2022). As the name suggests, SWIM is a concept that will use tiny swimming robots to explore ocean worlds, such as Europa and Titan. Exploring Europa's ocean in more detail will allow scientists to determine if the ocean already contains life or have conditions suitable for life, such as hydrothermal vents on the ocean floor. The goal of SWIM is to employ wedge-shaped robots around the size of a smartphone. They will be roughly five inches long and three to five cubic inches in volume. Because of their small size, around four dozen of them can be fitted into a 4-inch-long section of a cryobot. A cryobot is a robot that uses a high temperature nuclear battery to melt through layers of ice in order to reach the subsurface ocean. After these robots are deployed into the ocean, they can either swim off to different areas, or conduct research in a group. To achieve this, each individual robot contains a communication, intelligence, power, and sensing component (Greicius, 2022). Using large numbers of tiny robots like SWIM benefits missions by allowing larger areas of the ocean to be explored, and thus

increasing the possibility of finding life or conditions suitable for future human development. SWIM also allows more accurate data to be collected from different parts of the ocean as opposed to collecting data right from the cryobot, which may cause data to be inaccurate as the hot battery can produce chemical changes. SWIM is a very useful piece of technology that is being developed to enhance the productivity of future missions to ocean worlds.

Conclusion

Humans wish to explore habitable extraterrestrial objects to find a safe haven for future generations. While seemingly unlikely candidates in the outer reaches of the solar system, Titan and Europa have features that are promising for future humans to potentially inhabit. Titan has a dense atmosphere and an abundance of methane, as well as a possible subsurface liquid water ocean. Europa is speculated to have a huge liquid water ocean under its ice crust, and may also have pockets of warmer liquid water within its icy surface. NASA is planning to explore these two unique moons with the Dragonfly mission to Titan and Europa Clipper missions to Europa. New technology, such as Sensing With Independent Micro-Swimmers, is also being developed by NASA to increase the productivity of future missions. These missions will provide invaluable information about these moons, and further accelerate humanity's quest to one day live amongst the stars.

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